COMMENT

On horizons and the cosmic landscape

George F R Ellis
Mathematics Department, University of Cape Town,
Rondebosch, Cape Town, South Africa.

Abstract

Susskind claims in his recent book *The Cosmic Landscape* that evidence for the existence and nature of 'pocket universes' in a multiverse would be available in the detailed nature of the Cosmic Blackbody Background Radiation that constantly bathes all parts of our observable universe. I point out that acceptance of the complex chain of argument involved does not imply possible experimental verification of multiverses at the present time. Rather this claim relates only to theoretically possible observations in the very far future of the universe.

A recent book by Susskind [1] presents interesting arguments for the existence of multiverses. Much of that argument is based on quantum field theory and the non-zero but small value for the cosmological constant, and is not the concern of this comment, which focuses on issues to do with the nature of horizons in cosmology. The point I wish to make is that Susskinds' contentions about information flows and the Cosmic Background Radiation ('CBR') in his book do not imply possible astronomical confirmation of multiverses at any finite time in the history of the universe.

The multiverse proposal Susskind espouses states that there exist in a single big megaverse a vast number of "pocket universes" like the expanding universe domain we see around us, all beyond our observational reach as they are hidden behind the cosmological horizon. "Our cosmic horizon is about fifteen billion light-years away, where things are moving so rapidly away from us that light from there can never reach us, nor can any other signal. It is exactly the same as a black hole horizon - a point of no return. The only difference is that the cosmic horizon surrounds us, whereas we surround a black hole horizon. In either case nothing from beyond the horizon can influence us, or so it was thought. According to classical physics, those other worlds are forever completely sealed off from our world".[1] The significance is that this apparently means that claims of a multiverse are not susceptible to observational verification or disproof; hence their scientific status is open to question: "Unfortunately the rest of the megaverse of pocket universes is all in this never-never land beyond the horizon. According to the classical principles of general relativity, we can wonder all we want about the existence and reality of these other worlds, but we can never know. They are metaphysics, not physics" ([1], p.340; and see also [2]).

[1]This quote from [1] is taken from the Introduction, available on the web at *http : //www.twbookmark.com/books/28/0316155799/chapter_excerpt22014.html* .

Susskind counters this objection on the basis of what he terms "the Black Hole War" - the battle over the fate of information that falls behind the event horizon of a black hole. He states that the standard view that all information falling behind the event horizon is irretrievably lost, has turned out to be wrong. On the basis of a complex discourse involving the No Quantum Xerox Principle, Black Hole Complementarity, and The Holographic Principle, he makes the major claim that is the subject of this comment:[1] "The very same arguments that won the Black Hole War can be adapted to cosmological horizons. *The existence and details of all the other pocket universes are contained in the subtle features of the cosmic radiation that constantly bathes all parts of our observable universe*" (my italics).

Now I do not aim to adjudicate here as to whether the Black Hole War is won or lost: I simply accept for the sake of the rest of the discussion that information may not after all be lost when it has fallen behind the event horizon. The key point is that if this is so, it does not have the implications set out in the italicized statement in the previous paragraph, because *the limits on our present day causal connectivity in cosmology are due to the particle horizon, not the event horizon* [3, 4, 5, 6].

While it is true that "the cosmic event horizon of an eternally inflating universe is mathematically very similar to the horizon of a black hole" ([1], p.340), this has nothing to do with limits on information available to astronomers today; these are based on the cosmic particle horizon, which is quite different. The particle horizon in cosmology (limiting the 'particles' we can see at the present time) is defined in terms of world lines of matter, and depends on the epoch of observation; it strictly limits what information about matter we can access *at the present time*. Furthermore, it exists in any realistic (almost Friedmann-Lemaître) universe. By contrast, the event horizon in either cosmology or a black hole context (limiting the events we will ever be able to see at any time in our history) is defined by a limiting past null cone, and relates to the entire world line of the observer, not any particular observational epoch; whether it exists or not in a cosmological context is determined by the nature of the end of our history in the far future [3]. An event horizon will not occur in a cosmology that expands forever with cosmological constant $\Lambda = 0$ in the far future; it exists either at a 'Big Crunch' a finite time from now in the future in a $k = +1$ universe that recollapses, or at an infinite time in the future in a universe that expands forever with a non-zero cosmological constant (in each case there is a spacelike future infinity leading to the existence of the event horizon[2] [4, 5, 6]).

The criteria for existence of the two kinds of horizon in a Robertson-Walker universe with scale factor $a(t)$ are as follows [3]:

- a particle horizon exists if and only if at an arbitrary time t_0 in the universe's history, either the integral $\int_0^{t_0} dt/a(t)$ converges (if the universe started at time $t = 0$ where $a(t) \to 0$), or the integral $\int_{-\infty}^{t_0} dt/a(t)$ converges (if the

[2] In the black hole case, the event horizon is independent of the world line chosen, whereas in the cosmological case, different event horizons occur for world lines ending at different points on this spacelike future infinity.

universe has existed forever),

- an event horizon exists if and only if at an arbitrary time t_0 in the universe's history, the integral $\int_{t_0}^{\infty} dt/a(t)$ converges (if the universe expands forever in the future) or the integral $\int_{t_0}^{t_{final}} dt/a(t)$ converges (if the universe comes to an end at a finite time t_{final} in the future where $a(t) \to 0$).

These expressions show how the event horizon relates to the future (observational events yet to take place), whereas the particle horizon relates to the past (events that can send signals to be received by us today).

It is the event horizon that is at the centre of the Black Hole information loss paradox; if the resolution of this problem described by the author is correct, observers would become aware of any information escaping from their event horizon as they approached it in the far future of their histories. If information about what lies beyond a cosmological event horizon were indeed to emerge, this information would be available to us only at the very end of the universe. This possibility does not affect present day observations, which are fundamentally limited not by the event horizon but by the particle horizon - which excludes all information from other pocket universes in a supposed megaverse from reaching us at the present time (in essence: there has not been enough time since they were formed for light from them to reach us).

In reality, the limit is even stronger: no significant cosmological information reaches us at the present time from beyond the *visual horizon* - defined by the world-lines of the furthest matter from which we receive electromagnetic radiation today [7, 8].[3] This matter is seen by us as the matter that emitted the observed CBR at the time of decoupling of matter and radiation in the early universe. The possible far future occurrence of an event horizon in the universe will not influence CBR data available to us today, *inter alia* because that information is shaped by the interactions taking place in the primeval plasma after inflation and before decoupling, see e.g. [11]. Prior information is largely forgotten during this era - thermalization will destroy any subtle correlations that may exist at earlier times - and occurrence of an event horizon in the far future of this epoch is irrelevant. Possible other 'pocket universes' do not enter the calculations [11] of CBR anisotropies.[4]

In summary: The ESA-NASA Planck Surveyor data on CBR anisotropies will not have coded into it the nature of multiverse regions enormously more distant from us than a Hubble radius. Attempts to decipher information about far distant regions of a megaverse supposedly hidden in that data will not succeed. The black hole arguments of [1] potentially become relevant only at the end of our destiny when our past light cone merges with the event horizon, either at future infinity ($t \to \infty$ on our world line, with $\Lambda \neq 0$ in that limit), or at the final crunch in a recollapsing universe ($t \to t_{final}$ on our world line, necessarily with $k = +1$); they do not affect present day astronomy.

[3]This is not related to the matter moving away from us at the speed of light, as is often supposed (see [9, 10]).

[4]Discussions of 'super-horizon modes' and 'trans-Planckian effects', see e.g. [12], are all carried out in the context of a single Robertson-Walker universe domain.

References

[1] L Susskind: *The Cosmic Landscape: String Theory and the Illusion of Intelligent Design* (Litle Brown, New York. 2005).

[2] G F R Ellis: "Philosophy of cosmology". To appear in *Handbook in Philosophy of Physics*, Ed J Butterfield and J Earman (Elsevier, 2006), Section 9.2. (http://arxiv.org/abs/astro-ph/06022) .

[3] W Rindler, "Visual horizons in world models". *Mon Not Roy Ast Soc* **116** 662 (1956).

[4] R Penrose, "Conformal treatment of infinity". *Relativity, Groups and Topology* ed C M DeWitt and B S DeWitt (New York: Gordon and Breach, 1963), 565.

[5] S W Hawking and G F R Ellis,*The Large Scale Structure of Space-Time*. (Cambridge: Cambridge University Press, 1973), pp. 127-130.

[6] F J Tipler, C J S Clarke and G F R Ellis, "Singularities and horizons: A review article". In *General Relativity and Gravitation: One Hundred Years after the Birth of Albert Einstein, Vol. 2* ed A Held (New York: Plenum Press, 1980), 97.

[7] G F R Ellis and W R Stoeger, "Horizons in inflationary universes". *Class Qu Grav* **5**, 207 (1988).

[8] G F R Ellis and R M Williams. *Flat and Curved Space Times.* (Oxford University Press, 2000), Section 7.5.

[9] G F R Ellis and T Rothman, "Lost Horizons". *Am. J. Phys.* **61**, 93 (1993).

[10] T M Davis and C H Lineweaver, "Expanding Confusion: common misconceptions of cosmological horizons and the superluminal expansion of the Universe". *Publications of the Astronomical Society of Australia*, **21**, 97-109 (2004). (http://arxiv.org/abs/astro-ph/0310808) .

[11] S Dodelson, *Modern Cosmology.* (Academic Press, 2003).

[12] J Martin and R H Brandenberger, "The Trans-Planckian Problem of Inflationary Cosmology" (2005). *Phys.Rev.* **D63** (2001) 123501 (http:/arxiv.org/abs/hep-th/0005209) .

Version 2007-03-15.